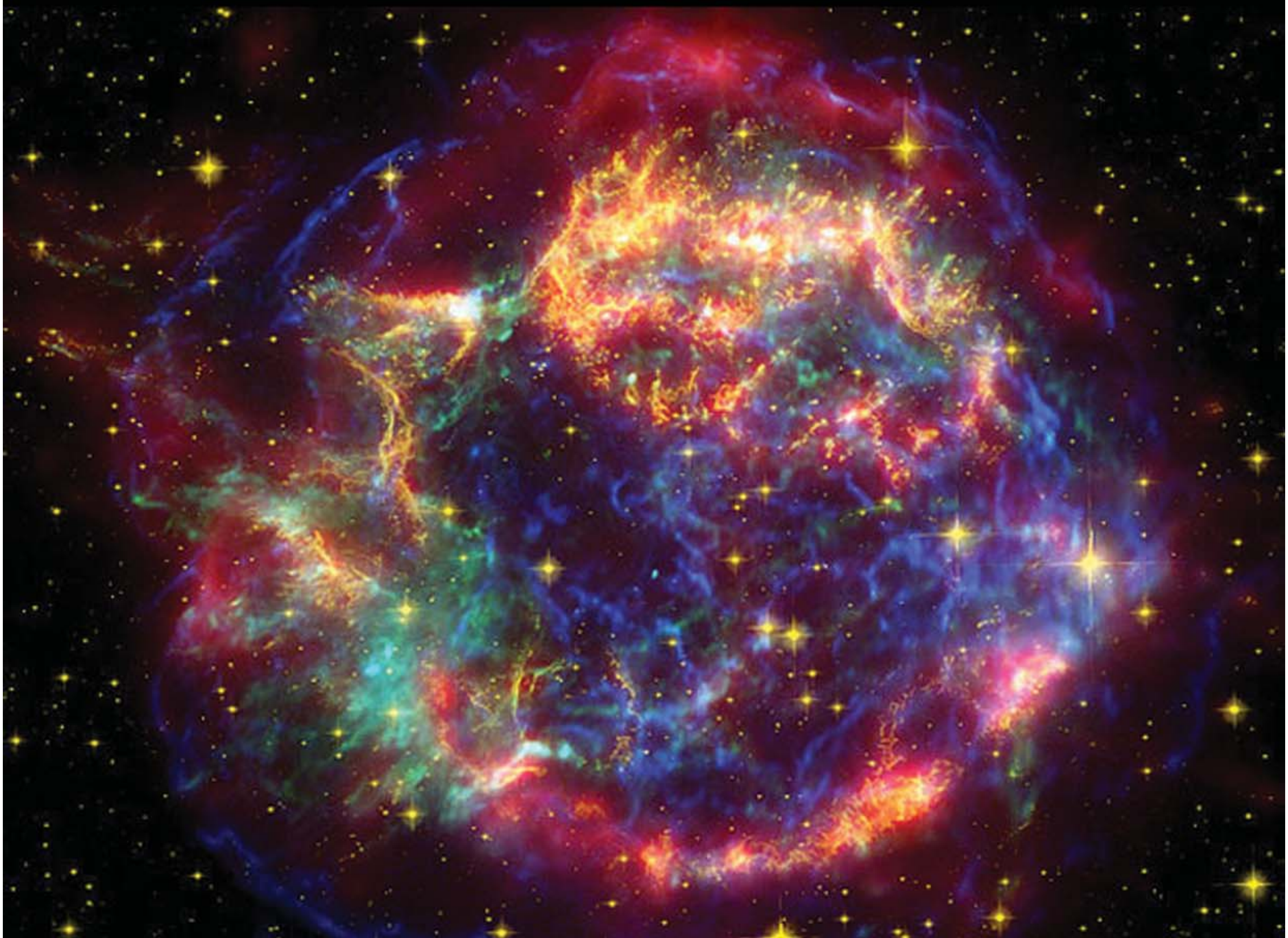
Big Explosions and Strong Gravity

Beta Version



Bringing Black Holes to Girls: A Manual for Running the Program

Fall 2008 Draft

Introduction

Big Explosions and Strong Gravity is a one day Girl Scout event during which girls earn a patch for the back of their sash or vest. It is designed to put actual scientists in the classroom with students. Although all the activities are gender-neutral, we have focused on girls due to their underrepresentation in science, and a fruitful partnership with a local Girl Scout council. We target a middle school age range due to the general decline in interest in math and science that occurs at or after children reach this critical age. It is our hope that this program helps us reach them early enough to have a positive effect.

During this event, girls explore the abundance of elements in the universe, spectroscopy, supernovae, and black holes in four sessions that run approximately 45-60 minutes each. Whenever possible, these sessions are led by professional astronomers, engineers, and graduate students in related fields. We recognize that in most places there are not enough local scientists available to make this practical. In these cases, we strongly encourage prospective organizers to involve at least a few such people, and have them interact with the students. Even if insufficient numbers of scientists and engineers are available in your area for them to lead all the classrooms, it is possible to achieve this program with all of its benefits with only a few people.

This event has been run four times over the years 2004-2008 with the Girl Scouts of Central Maryland. Thanks to a NASA ROSES grant, we are now working to expand this program nationally. In late 2008, it will be run in the Girl Scout Council of the Nation's Capital. During 2009 we will expand our pilot effort to include approximately 5 new locations around the country.

This manual, currently in "beta" form, is being developed to assist in expanding this program nationally, and to make it easier for people who are less familiar with the activities to organize the program and run the sessions. Although the sessions are listed in a certain order within this manual, there is no set progression that the students must follow. The first two activities provide a good basis for the last two, but within those pairings, they can be done in any order. More explanation of this is included in the section on how to run this program.

This program was originally developed in the Johns Hopkins University Department of Physics and Astronomy, with participation from members of NASA Goddard Space Flight Center and the Space Telescope Science Institute, as well as the Girl Scouts of Central Maryland. It is currently administered by Dr. Ann Hornschemeier and Ms. Sarah Eyermann, both of NASA Goddard Space Flight Center.

Please visit our website at http://bigexplosions.gsfc.nasa.gov/ for more information. If you have any questions, please email bigexplosions-qa@majordomo.gsfc.nasa.gov. We always appreciate feedback and suggestions.

Contributors

We wish to recognize the contributions of the following scientists who have contributed significant time to the development of BESG activities and to the activity write-ups.

Dr. Lynn Carlson – Johns Hopkins University
Dr. Lori Feaga – University of Maryland
Dr. Saavik Ford – SUNY, ???
Dr. Rajib Ganguly – University of Wyoming
Dr. Anita Krishnamurthi – University of Maryland and NASA GSFC
Dr. Jeff Livas – NASA GSFC
Dr. Jim Lochner – NASA GSFC
Dr. Edward Wollack – NASA GSFC

We also wish to acknowledge the above-and-beyond administrative help of Ms. Sheryl Falgout (JHU 2003-2004, now at NOAO) for her assistance in getting this program started.

Acknowledgements

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Support from the side of the Girl Scouts of Central Maryland comes from another Cycle 9 Chandra X-ray Center E/PO grant (Adding Loops To The STEM Pipeline: Mentoring and After-School Activities for Girls Scouts, EPO Proposal/Approved CXC Science Proposal # 9620513).

The success of this program has only been possible due to the assistance of many people and groups. We would specifically like to acknowledge the following:

- Chandra X-ray Center for donating calendars, board games, bookmarks, postcards and other items
- JHU Department of Physics and Astronomy and Catholic University of America for donating space for activities and storage
- Girl Scouts of Central Maryland Girl Scout council for assisting us with the development and testing of this program

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Summary

Big Explosions and Strong Gravity is a one day Girl Scout event during which girls earn a patch for the back of their sash or vest. It is designed to put real astronomers in the classroom with students. In this event, girls ranging in ages from 11 to 13 will participate in hands-on activities designed to give them a better understanding of the abundance of elements in the universe, the spectrum, supernovas, and black holes in four sessions that run approximately 45-60 minutes each. Whenever possible, these sessions are led by professional astronomers, engineers, and graduate students in related fields. The four activities are as follows:

<u>Elements and You</u>
Students are introduced to the periodic table and the concept of elements. The group will discuss how all material in the universe is composed of elements and that the atom is the smallest particle which still has the physical and chemical properties of any given element. As an exercise in statistics, the students will participate in a counting experiment, sampling the universal trail mix, to estimate the bulk composition of the universe. Finally, the idea of fusion is introduced with respect to creating heavier elements from hydrogen inside a star.

<u>Rainbow Analysis</u>
Students are introduced to the scientific tool of spectroscopy. They will each build a simple spectroscope so that they can examine the light from different light sources, particularly the Sun (if logistically feasible) and artificial lights (fluorescent or sodium lamps, discharge lamps, or whatever is available locally). The solar spectrum will appear continuous at the resolution typical of plastic diffraction gratings; however the fluorescent or sodium room lights and discharge lamps will show clear lines (students often describe the spectra as "broken up"). These lines represent the "fingerprint" of the element contained in the lights and are always the same, no matter where the element appears or how much of the element is present. Appearance of a fingerprint in the spectrum of a distant astronomical object demonstrates the existence of that substance in the object. The discharge lamps provide the opportunity to show students a variety of spectral fingerprints.

<u>Supernova Explosions</u>
Students are reminded that the universe is made up of elements and that the heavier elements are created inside of a star. They are introduced to the life cycle of a star and how the mass of the star affects the process of fusion and the outcome of the star. The physical concept of balancing forces is discussed and an experiment is conducted to show what can happen to a soda can when the interior and exterior forces are not in equilibrium. An analogy is made between this experiment and core collapse in stars. Finally, it is demonstrated how mass can be ejected from a collapsed star. This is how the heavier elements are dispersed throughout the universe in a supernova explosion.

Black Holes in Orbit

Students are introduced to the basic properties and behavior of black holes through a brief discussion, including how it might be possible to detect black holes through their interaction with other stars. Then they "act out" binary star systems in pairs, walking slowly around one another in a darkened room with each pair holding loops of wire to simulate the gravitational interaction. Most of the students are wearing glow-in-the-dark headbands to simulate stars. Some are not wearing headbands and represent black holes. A small set of the black holes have flashlights to simulate X-ray emission.

This program was originally developed in the Johns Hopkins University Department of Physics and Astronomy, with participation from members of NASA Goddard Space Flight Center and the Space Telescope Science Institute, as well as the Girl Scouts of Central Maryland. The Rainbow Analysis, Elements and You, and Supernova Demo activities were either taken from or inspired by the Imagine the Universe lesson plan on supernova spectroscopy. The black hole orbits activity was adapted from an Adler Planetarium activity.

How to Run this Program

FIND A PARTNER

So you're a Girl Scout council and you think this would be wonderful for your girls to experience. Or you're a scientist and you want to help bring these activities to girls in your area. The first thing you need to do is to find a local partner. This program works best as a partnership between a Girl Scout council and space scientists. If you are a Girl Scout council, try talking to the physics department at universities in your area, as well as any science or engineering company. If you are a scientist, you can find out how to contact your local Girl Scout council through the Girl Scout website at http://www.girlscouts.org/councilfinder/.

FIND A LOCATION

Once you have a partner, you need a location. We have successfully run this event at a Girl Scout facility and at a university physics department.

Space and other requirements to keep in mind when picking your location:

- At least 4 rooms total are necessary.
- At least 1 room big enough for everybody to gather is also necessary. There is some advantage to having this be a 5th room instead of one of the 4, but this is not necessary.
- At least 2 of the rooms must be able to be completely darkened.
- Two rooms, which also must "dark-ready" rooms, also need space for people to move around without bumping into desks, etc.
- There must be additional space (the other two rooms or a space outside, in a hallway, etc) for getting up and moving around and playing with balls. The balls also shouldn't be able to hurt anything/body when they bounce around.
- It is best if the rooms are not too spread out so that people do not get lost going between them.
- Ideally, noise should not carry greatly between the rooms, to avoid the different groups disturbing each other with their noise.
- Make sure there's sufficient free parking available.
- Make sure that any necessary steps are taken with the security at your location to ensure that everybody can reach the location on that day (access to location, buildings locked, etc.) and that there will be no problems with security while you are there.

SET A DATE

You may need to set your date six months in advance, or even more, in order to get on calendars and the appropriate advertisement lists. There are several things you should keep in mind for setting a date.

- You probably need a full day, so a Saturday is probably best.
- Make sure there are no other events going on in the Girl Scout council or at your location that will be serious competition for volunteers or attendance, or will get in your way at the location. Girl Scout staff are very helpful with checking council calendars, and there will be a contact at your location that will have the calendar for that location as well.
- Avoid holidays that might be competition.

FIND VOLUNTEERS

You need two types of volunteers: the science volunteers and the general volunteers, which can be anybody, including scientists if you have enough of them. The more scientists you can get in the room with the girls, the better. The first several times we ran this program, our volunteer staff almost entirely consisted of scientists, but we recognize that this will be hard to replicate in most areas.

The scientist volunteers serve two functions for this event. First, they understand the background and can teach other volunteers what they need to know in order to successfully talk about the science side of these activities with the girls. Second, they provide an opportunity for the girls to meet real live scientists/engineers (hopefully including some female scientists/engineers), talk to them about what their career is like, and start to realize that scientists and engineers really are people too. These two functions can easily be served by the same scientists, or different ones, depending on schedules and availability.

When we have run this program, we have set an upper limit of 100 girls, and then divided them into 4 groups. We recommend no more than 25 girls at a time in a group. We also recommend at least 3 volunteers with each group of 25 girls, so the minimum number of volunteers you would need would be 12 (or twice that if your volunteers only work half days). It is helpful to have extras to take care of lunch and any necessary rearranging, etc, while the girls are still busy with activities.

TRAIN VOLUNTEERS

As mentioned above, you need to make sure that all of your volunteers are familiar with the science behind the different activities. This means a training session for volunteers without the necessary science background. Even if all your volunteers are subject matter experts, we still highly recommend practicing or rehearsing the activities and making sure they are prepared for all questions. Presenting to middle-school aged children requires preparation, even for scientists.

When we have run this program we have had two activities in the morning, and two in the afternoon. For 100 girls, you should have at least 6 volunteers who understand each morning activity, and 6 who understand each afternoon activity (2 parallel groups of 25 for each activity). If volunteers are staying all day, they can do both a morning and an afternoon activity. These numbers may change if you run this program with a different schedule/format than what we have used. Scheduling options are discussed later.

We suggest that for the training, the scientists run the activities with the general volunteers acting as the students. Scientists should emphasize the science explanations during the training, as that is most likely the part that somebody with no science background will struggle with, whereas they may be quite experienced at dealing with Girl Scouts of this age.

HANDOUTS AND "PRIZES"

We have always provided the girls with a folder of handouts in the morning when they first arrive. While this is not necessary, we think this adds a nice touch. You can get astronomy handouts from many different educational resource providers. A very easy and very appropriate option is NASA's Chandra X-ray Observatory program. They will happily provide free resources for an event such as this. Their request form can be found at http://chandra.harvard.edu/edu/request.html. Make sure you allow at least 3-4 weeks for the materials to reach you.

Another useful item to include in this folder of materials is a periodic table. This can be helpful for the discussion in Elements and You session. This folder also provides a useful place to include the schedule for the day, evaluation forms, and anything else the girls might need to read or fill out. Free periodic tables can be downloaded from a number of sites online. Options for where you can order large quantities of periodic tables are listed in Appendix B.

It can also be nice to have small little prizes (space stickers, bookmarks, postcards, posters, etc) to encourage girls' participation in discussion, and to give as prizes for completion of certain activities, such as the scavenger hunt. Again, these are not necessary, but the girls love them.

In the past we have included t-shirts as part of this event. After conducting a survey about event costs, we learned that girls and parents do not consider this very important. As they added to the complexity and expense of the event, we have decided to forgo them. You, however, are free to choose differently. We have a graphic available that does not have a specific date on it, so that if used, the leftover shirts are usable for future events.

While we have determined t-shirts to be unnecessary, the Girl Scout patch is more important. Girl Scouts display this on their vest to show that they have completed an event or activity, and they will be disappointed if such is not available.

LUNCH

Since this is an all-day event, it is important to make provisions for lunch, both for the girls, and for the volunteers. It might be prudent to provide something simple in the morning for the volunteers as well, but this is up to your discretion.

SCHEDULE

Although the sessions are listed in a certain order within this manual, there is no set progression that the students must follow. The first two activities provide a good basis for the last two, and so we recommend that they be done first, but within these pairings, they can be done in any order. Each session is designed as an individual recipe, and therefore could be run independently of the others.

When we have run this program, we have had a target number of 100 participants. These we divide into four groups. They stay within their group for the entire day. For the first session of the morning, two of the groups participate in Elements and You, and the other two in Rainbow Analysis. After the first hour, they switch, and those who had done the Elements and You unit do Rainbow Analysis and vice versa.

After the morning activities, we do an activity relating to black holes just before lunch. This activity has changed from year to year, and has included a quiz show designed by other Girl Scouts, a video about black holes, a black hole maze, and others. During lunch we have included a scavenger hunt. The point of this is to let the girls interact with scientists/engineers to see that they are real people too. The questions relate to hobbies, family, history, and life in general. You may edit these questions however you want, but an example we have used can be found in Appendix D.

In the afternoon, the girls again divide into their four groups. Two groups do the Supernova Explosions activity and the other two do the Black Holes in Orbit activity. After another hour, they switch in the same manner as before. An example of the schedule we have used for this event can be found in Appendix C.

SOME TIPS FOR THE DAY

At the beginning of each session after the first, ask the students what they just learned, or what they have learned so far today. This will help them with retention of the knowledge they have gained.

Use volunteers from among the girls to pass out handouts, help demonstrate, etc. This helps with getting them up and moving, and also getting them engaged.

PHOTO RELEASE

You may need a photo release from each girl's parents in order to use photos from these events, since these girls are minors. Most Girl Scouts will have one of these on file for each girl, but you will need to check whether this will extend to any agency other than the council. We would love to receive photos of your event for inclusion on our website and in other places. In order for this to be possible, we need a copy of the NASA photo release form signed by a parent for each girl, in addition to any forms needed from your end.

Suggestions for Leading Middle-School Aged Girl Scouts

Many scientists and engineers may not have experience interacting with this age group. While they may be accomplished teachers in a university setting, there are some key differences in how to successfully interact with middle-school aged children instead of adults or even high-school aged students. Additionally, there are specific points to consider when working with Girl Scouts.

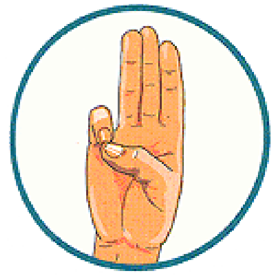
1. Whenever possible, engage the students' participation. Ask them questions; involve them in demonstrations; etc. Make it an interactive experience.

2. Do NOT lecture. You will lose their interest almost immediately. If you feel that the material calls for a lecture, see the previous point, and make it as involved for them as possible. Find a reason to get them up every few minutes or so, even if it's just to pick up a piece of paper and sit down again. Even something as minor as this keeps them from zoning out.

3. Get them up and moving around whenever there's an opportunity. Even things as simple as having a volunteer up for a minute to demonstrate something, or walking up to the front of the room to retrieve a worksheet or image will keep them more involved and therefore more engaged.

4. Girl Scouts frequently come with parents who will attend such events with the girls. This can be very useful in maintaining order among the girls, and you should feel free to use these parents for that purpose. The downside of having ever present adults is that they can feel the need to jump in with answers if the girls are shy or uncertain and taking a while to come up with a response to a general question. You should gently discourage this, as this activity is designed for the girls' benefit rather than their parents, and it may even be helpful to have alternate activities for them to be engaged in instead.

5. Girl Scout culture has an established method of quieting a noisy room that can be used to your advantage. When you hold your hand in the air in the Girl Scout sign (3 fingers up) as pictured to the right, this is a sign to the room to be quiet. As each person in the room sees this, they too will hold their hand in the air in this manner, until the entire room has caught on. The key part of this is that when one holds their hand in the air in this manner, one is not allowed to speak. THIS INCLUDES THE PRESENTER, so do not hold your



hand up and continue speaking. Once the entire room has gone silent and all hands are in the air, you may lower your hand and speak to the group.

6. Girl Scouts frequently want to know what badge requirements they might be able to complete, so be aware that you may be asked related questions at the end of your presentation. You should certainly discourage any such questions at the beginning of the session or during. We will try in an upcoming revision to include some notes points in these activities where they might meet their requirements, but it will certainly not be an exhaustive list. However you choose to deal with this eventuality, you should at least be forewarned that it may take place.

Elements and You Talking Points

These are some ideas for how to get the discussion rolling at the beginning of this session. Ask the questions (or ones of your own) and see what their ideas, preconceptions, and level of knowledge are.

Questions to ask:

Elements and You

Summary

Students are introduced to the periodic table and the concept of elements. The group will discuss how all material in the universe is composed of elements and that the atom is the smallest particle which still has the physical and chemical properties of any given element. As an exercise in statistics, the students will participate in a counting experiment, sampling the universal trail mix, to estimate the bulk composition of the universe. Finally, the idea of fusion is introduced with respect to creating heavier elements from hydrogen inside a star.

Purpose

To introduce the idea of an element, the abundance of different elements in the universe, and the role of fusion in a star.

Audience

Approximately 20 students (grade range 6^{th}-9^{th}) in a group works well

Objectives

- To understand what an element is
- To become familiar with a periodic table and common elements
- To determine the most abundant element in the universe
- To learn how heavier elements form from fusion
- To gain knowledge of the processes in the interior of a star

Badge Requirements

-

Materials

- Example of a pure element (sheet of aluminum, copper tubing, etc.)
- 1 plain pound cake for demonstration
- 1 knife to cut the pound cake
- Napkins or paper plates for pound cake demonstration (1 per student)
- 1 large periodic table for display (if possible 1 small one per student)
- Scoops or Dixie cups for the trail mix demonstration (1 per student)
- 1 large mixing bowl
- 1 large bag of rice for the trail mix
- 1 small bag of unpopped popcorn kernels for the trail mix
- 1 small box of macaroni for the trail mix
- 1 small bag of uncooked beans for the trail mix (black beans worked well)
- 1 small bag of uncooked black-eyed peas for the trail mix
- 1 jar of multi-colored cake decorating sprinkle shapes
- 1 transparency of trail mix ingredients and what element they represent
- 16 lbs of red modelling clay (4 pounds per sphere = 32 sticks, to represent hydrogen)
- 8 lbs of yellow modelling clay (2 pounds per sphere = 16 sticks, to represent helium)
- 4 lbs of orange modelling clay (1 pound per sphere = 4 sticks, to represent carbon)
- 2 lbs of green modelling clay (1/2 pound per sphere = 2 sticks, to represent magnesium)
- 1 lb of blue modelling clay (1/4 pound per sphere = 1 stick, to represent iron)
- 1 transparency of model star clay colors and what element they represent
- 1 trash can or trash bag

Preparation

1. Universal Trail Mix: ~15 minutes

   Mix the ingredients ahead of the planned activity in a large bowl. Use the same size "measuring cup" for preparation as the students will each have during the activity. Mix the following:

   - 40 scoops of rice (to represent 89% abundance of hydrogen in universe)
   - 4 scoops of corn (to represent 9% abundance of helium)
   - 2 scoops of macaroni (to represent 0.75% abundance of carbon)
   - 2 scoops of beans (to represent 0.75% abundance of oxygen)
   - 1 scoop of black-eyed peas (to represent 0.25% abundance of nitrogen)
   - 1 scoop of sprinkles (to represent 0.25% abundance of all other elements)

2. Clay star: ~ 2 hours to assemble

   Make the clay star in 5 color coded layers. We found pre-cutting the ball as the layers were added to be helpful. The layers are as follows:

   - The interior clay ball will be blue in color ~ 2 inches in diameter
   - The next layer will be green in color with a shell thickness of ~ 1 inch
   - The next layer will be orange in color with a shell thickness of ~ 1 inch
   - The next layer will be yellow in color with a shell thickness of ~ 2 inches
   - The next layer will be red in color with a shell thickness of ~ 2-3 inches

   Make extra fusion demonstration small clay balls
   - 2 red ~ 1 inch in diameter for hydrogen
   - 2 yellow ~ 1.5 inches in diameter for helium
   - 1 orange ~ 2 inches in diameter for carbon

3. If using lead, or another potentially harmful substance, wrap it in plastic or otherwise prevent the students from handling it directly. Anybody who does handle it should wash their hands afterwards, and certainly before they eat or drink anything.

Activity

This activity can be completed in 45 minutes. A sample script and flow of discussion follows.

I: Poundcakium *(approximately 15 minutes)*

What is an element?

We'll start this activity with a freshly made pound cake. Let's pretend we just discovered this element. We'll call it "Poundcakium". What are some of its characteristics? Let the students answer.

This loaf of poundcakium is all one flavor, texture, and color.

Let's cut the loaf of poundcakium in half. What do we have now? We still have poundcakium, albeit two pieces of it. Let's cut it in half again, what do we have? That's right, still poundcakium. As we continue to cut this poundcakium in half, we eventually get to the smallest piece of poundcakium, and that is a single crumb of poundcakium. We have not destroyed or created any poundcakium as we divided it into smaller pieces.

Can anybody think of any examples of elements that you know? Allow them to answer. If they need prodding, suggest categories, such as 'things around us in the room,' 'things in your home,' 'metals used for money or jewelry,' etc. Guide the conversation, but let it go where they take it.

Things we are familiar with can be made up of many elements, or ingredients. Some are pure substances like a gold bar or a silver chain. Some are made of many ingredients. Pound cake (as opposed to our imaginary poundcakium), for example, is made of ingredients. Let one student read the ingredient list. The ingredients just read like flour, sugar, milk and eggs are made of elemental ingredients like carbon and hydrogen.

Hand out pieces of the pound cake to the students as a snack.

Have a volunteer student come up and try to cut the lead brick (or other sample of a pure element). They won't be able to.

Lead is very hard to cut, but we could imagine doing essentially the same experiment with a lead brick. If I were to cut the brick in half, would I have changed what the brick is made of? Let the students answer.

No, the brick would still be lead, and the total mass would still be the same as when we started, but it is now in two pieces. Since lead is an element, no matter how many times I might cut the lead brick in half, I will always be left with lead. We could cut the lead brick in half and in half again until all we were left with was a single atom of lead. An atom is the smallest piece of lead, or any element, that we can have that still has the same properties as the original piece.

An element is a chemically pure substance composed of atoms of a single type. Elements are the building blocks for all matter, everything that we can see and touch. Lead is an element which we can find naturally occurring on the Earth. All lead atoms are the same.

The elements known to scientists are cataloged into a table called the periodic table of elements. Some of you may have seen or used a periodic table before. The elements in rows and columns of the tables have common traits or characteristics. Each element is different from the next in many measurable ways. Some are solid, some are gas, and some are liquid. They each have a unique mass. They can all be described with qualities like hardness or softness.

One way you can tell different elements apart is to look at a spectrum of the element. A spectrum is like the element's signature or fingerprint. You can participate in the Rainbow Analysis activity and look at the spectrum of hydrogen, oxygen and other elements to see examples of the differences in signatures.

You each have a periodic table to look at. Do you recognize any of the elements? Let the students answer. *What is your favorite?* Let the students answer. *Do you see any in this room?* Let the students answer.

Some elements are common to us in their pure form, like silver or gold. Some are common to us in compounds like salt (NaCl) or water (H_2O).

II: Universe Trail Mix *(approximately 15 minutes)*

What is the most abundant element in the universe? Let the students give some guesses.

If we were to grab a handful of space particles, what would we have? Let the students give some guesses.

I have here some Universe Trail Mix to simulate the elements in space. Each one of you will take a scoop of the Universe Trail Mix back to your seat, and you will count or estimate how much of each Trail Mix ingredient (element) you have on the napkin provided. Give the students 5-10 minutes to get a scoop, return to their seats and to inventory their ingredients.

Make a tally of the ingredients from each student or group. Ask either how many pieces of each ingredient the students have or ask how many students have at least one piece of a certain ingredient.

You should all have mostly rice, some corn, and very few of the others.

The most abundant element in the universe is hydrogen, the first element on the periodic table. Almost 90% of the universe is hydrogen. The second most abundant element is helium. Nearly 10% of the universe is helium. All of the other elements exist in much lower abundances, much less *than 1%. Carbon, nitrogen, oxygen, magnesium, silicon, and iron are some of the common and more abundant heavier elements in the universe.*

What are your bodies are made of? Let the students answer. *Water (which has a lot of oxygen!), carbon, nitrogen, etc. How did we come to have this rich selection of elements on Earth? How do we go from mainly hydrogen and helium to all of these elements we need to build people and plants? You need a hot, dense environment to take hydrogen and helium and make something else. Where are the hot, dense environments? Any guesses?* Let the students answer.

III: Fusion (approximately 15 minutes)

What do you know about atoms? Let the students answer. [If they don't mention protons and electrons, we just leave them out. But if they do mention them, then as needed we can include them (i.e. different elements determined by number of protons).]

Where do the elements come from? At the big bang, we start with H (hydrogen) and He (helium). This is partly why there is so much of it in the universe.

But where did everything else come from? They come from stars, but how?

Where is it always hottest in the star? Let the students answer. *The center of a star is very hot - millions of degrees - and rather dense. The hottest stuff and thus the heaviest element formation is always in the middle of the star. There's lots of H in the center, and these H atoms bump into each other. Often a pair of these H atoms will stick together. Scientists call this fusion.*

Have a student volunteer come up. Show the small clay balls representing hydrogen, and let the volunteer stick the pair together. *The process of fusion releases energy. And, it is this energy that makes the sun and all other stars shine.*

But when H fuses, it forms a new element. It forms He. Ask for another volunteer to come up. Now bring up a different color clay ball that represents helium. Let the student hold the helium clay ball. Explain that if you could change the color of the H clay balls as they join, you'd get this second color.

Although there is a lot of H in the star, at some point the H in the center runs out. When this happens the core of the star shrinks. This increases the temperature. Now the He can start fusing. When He fuses, C (carbon) forms. Let the second volunteer stick two helium clay balls together. Then, bring up the last small clay ball representing carbon.

This continues until the He runs out. For stars like our Sun, this is where the process stops. But in stars much more massive than our sun, the process continues.

[To compare the mass/size of the Sun to that of Earth, the Sun's mass is 330,000 times that of the Earth; the Sun's volume is 1.3 million times that of the Earth. To compare the mass/size of a large star to that of the Sun, these can be 15 times more massive than the Sun, and have volume 4000 times that of the Sun.]

The carbon fuses together to form Mg (magnesium). C and He can fuse together to make O (oxygen). Different elements can fuse together to make new elements.

This process continues in massive stars until iron is created. In the core of a star, iron can't fuse into anything else and the reason is this. In all of these fusion processes, energy is being released, and the star stays hot and gives off light. But in order to fuse iron, energy is required. That means you have put in energy instead of getting energy out. [If they ask why this is so, it's because Fe (iron) is the most stable of the nuclei, and the process of fusion takes less stable nuclei to more stable nuclei.]

So at the end of its life, the center of a massive star will have an iron core and looks like this. Cut open the large model star clay ball. Have a volunteer student carry one half around the room so that each of the students can see it up close while you hold the other half for all to see. *All the elements that the star has created in its lifetime are inside the star. The colors of clay used in this model are not necessarily the color of the elements or the star. They are just bright colors used for the demonstration. If you participate in the Supernova activity, you'll see what happens next. In particular, how the elements get out of the center of this star and into space (where they eventually can become part of the earth and you and me).*

Universe Trail Mix Worksheet

INGREDIENT	ELEMENT	HOW MANY?
Beans	____________________	____________
Black-eyed Peas	____________________	____________
Corn	____________________	____________
Macaroni	____________________	____________
Rice	____________________	____________
Sprinkles	____________________	____________

Rainbow Analysis Talking Points

These are some ideas for how to get the discussion rolling at the beginning of this session. Ask the questions (or ones of your own) and see what their ideas, preconceptions, and level of knowledge are.

Questions to ask:

What do astronomers study?

How do astronomers learn anything about the above responses?

So, do we take pieces of stars and planets and put them under a microscope in our lab?

What do you think is the most distant astronomical object from which we have returned a sample?

- Right now it's a comet tail
- We also have collected samples from the moon
- Soon we will add Mars to this list

So since we don't collect pieces of distant objects, how do we learn about them?

- Lead a discussion about using light as a tool

Rainbow Analysis

Summary

Students are introduced to the scientific tool of spectroscopy. They will each build a simple spectroscope so that they can examine the light from different light sources, particularly the Sun (if logistically feasible) and artificial lights (fluorescent or sodium lamps, discharge lamps, or whatever is available locally). The solar spectrum will appear continuous at the resolution typical of plastic diffraction gratings; however the fluorescent or sodium room lights and discharge lamps will show clear lines (students often describe the spectra as "broken up"). These lines represent the "fingerprint" of the element contained in the lights and are always the same, no matter where the element appears or how much of the element is present. Appearance of a fingerprint in the spectrum of a distant astronomical object demonstrates the existence of that substance in the object. The discharge lamps provide the opportunity to show students a variety of spectral fingerprints.

Purpose

To teach students how astronomers determine the composition of distant objects.

Audience

Approximately 20 students (grade range 6^{th}-9^{th}) in a group works well

Objectives

- To understand that light is composed of different wavelengths
- To recognize that light can be separated by wavelength, which is equivalent to color
- To build an astronomical tool, specifically a spectroscope, to study light
- To learn that elements and molecules each have a unique "fingerprint" of lines at different wavelengths

Badge Requirements

Materials

- empty paper towel tubes (1 per student)
- aluminum foil (2 pieces at 3 x 5 inches and 2 strips at 1 x 3 inches per student) (measurements are approximate and do not need to be exact)
- masking tape
- diffraction grating (approximately 1 inch square of material per student)
- example spectrum (e.g. poster from Spitzer Science Center at http://www.spitzer.caltech.edu/)
- discharge lamps (optional, H, He, Ar, O, and CO_2)
- completely blacked-out room (optional)

Preparation

1. Prepare parts of spectroscope: approximately 30 minutes

   Cut pieces of foil and diffraction grating. Collect a paper towel tube, 2 pieces of foil 3 x 5 inches and 2 pieces of foil 1 x 3 inches, and a 1 inch square of diffraction grating for each student. You can put each kit in a Ziploc bag.

2. Darken the room: approximately 10 minutes (depending on room)

The room should be capable of going from brightly lit to dark so that both the overhead fluorescent lamps and the narrow discharge lamps can be seen effectively. Sometimes this means lights or light leaks must be covered. Dark black plastic trash bags and duct tape have proved useful for this.

Activity

This activity can be completed in 45 minutes. A sample script and flow of discussion follows.

I. Discussion

Ask if students know what a "spectroscope" is:

spectro – from spectrum, or rainbow (show example from e.g. a NASA poster)
scope – a viewing instrument, as in telescope or microscope
spectroscope – an instrument for viewing spectra

II. Construction of the spectroscope *(~ 20 minutes)*

1. The spectroscope has two ends, one for the diffraction grating (which is the end you look through) and one for a slit, which controls the entry of light into your instrument, so you can select which object to look at, and to improve the dispersion of light into a longer spectrum. We will assemble the grating end first.

2. Students should take a piece of aluminum foil about 3x5 inches and tear or cut a small hole in the center of the foil. The hole should be *smaller* than the square of diffraction grating material. The easiest way to do this is to fold the foil square in half (more or less), then half again the other direction. Tear off the corner that is at the center of the foil, and unfold it. Then unfold the foil – voila!

3. Next the students should tape the diffraction grating over the hole, being careful not to handle the diffraction grating too much, and to tape only the edges of the grating, not across the middle.

4. Students should then take the foil mounted grating, and put it over one end of the paper towel tube (with the grating over the hole) and tape the foil to the tube with masking tape.

5. Next we will assemble the slit end of the scope. Students should take the other piece of aluminum foil (about 3x5 inches) and put a hole in the center of the foil as before (if the hole they made the first time was a little too large for the diffraction grating, the piece of foil can probably be recycled for the slit end).

6. Students should take the two strips of aluminum foil and carefully fold each of them (so the strips are now about 1x1.5 inches) making a sharp crease at the fold (the crease is the important part, so don't worry too much about the dimensions).

7. Take the two creased pieces of foil and lay them over the hole in the large piece of foil – the two creased edges should be next to each other but not overlapping – a gap of a few millimeters (or perhaps the width of a toothpick) is perfect. Tape the two creased pieces of foil in place over the hole (but make sure that the tape isn't covering the gap) and place the slit over the open end of the paper towel tube and wrap the aluminum foil around the tube - BUT DO NOT TAPE THE SLIT TO THE PAPER TOWEL TUBE YET!

8. Now we need to "calibrate" (or precisely adjust) our spectroscope – we want to align our slit with the diffraction grating so that we get a wide spectrum which will be easy to see. Hold the spectroscope so that you can look through the diffraction grating end (the plastic square should be about as close to your eye as your glasses lens or as close as you would put a microscope). Point the slit end of the spectroscope towards a light source – this can be a light in the room or if you are outside, at the SKY, but **NOT the SUN!** Look for a rainbow in the spectroscope, probably a little bit off to the side or up or down (you should be able to see regular light from your source coming through the slit, but the rainbow will be off-center). While still pointing your spectroscope at the same light source, twist the slit around until the rainbow is as "fat" or "tall" as you can make it. Then, tape the foil for the slit end into position.

9. That's it! Make the point to the students that since they've built this spectroscope themselves, they know how to fix it if it breaks – if the aluminum foil tears, or they accidentally sit on their paper towel tube, or some of the tape comes off, they can fix it themselves!

Remind them NEVER to look at the sun!

III: Using the spectroscope *(~ 20 minutes)*

1. Now that the spectroscopes are built, it's time to put them to some use – the first object students should look at (if at all possible) is a spectrum of the sun.

   IMPORTANT WARNING: NEVER LOOK DIRECTLY AT THE SUN WITH THIS INSTRUMENT OR YOUR NAKED EYE.

   Instead of looking directly at the sun, we can look at the sky, which is bright from sunlight scattered off of little bits of dust in the air. This should be possible even if it is fairly cloudy; however it may not be feasible if it is actually raining, in which case an incandescent bulb can be substituted. You should point out that the solar spectrum (at this resolution) is a fairly uniform rainbow, showing all the usual colors (the students will usually remember and recognize ROY G BIV).

   Now is also a good time to point out (in conjunction with a spectrum poster) that the spectrum really extends beyond what the students can see in their spectroscopes, to "invisible light", like radio, infrared, ultraviolet, X-ray, etc. This is similar to sound of a dog whistle – the sound a dog whistle makes is real, and with the proper kind of ears we could hear it. Radio, IR, UV, X-ray, and other wavelength ranges of light are real, and with the proper kind of "eyes" or cameras, we can see these other wavelengths of light. If you think of light in terms of keys on a piano, the light we can see is only the keys from middle-C up to E—less than a full octave. Everything else is invisible light.

   Different colors that the students see represent different wavelengths of light, but visible light wavelengths have a very narrow range – only about 300-700 nanometers (a nanometer is a billionth of a meter) – while wavelengths of light can range longer than meters in the radio to shorter than a picometer (trillionth of a meter) for gamma rays.

2. Next, students should examine a light source with obvious discrete lines – most schools and other institutional buildings have bright mercury fluorescent lamps, which are ideal. If

you are unsure of what kind of lamps you have, build yourself a spectroscope in advance and have a look around – descriptions of the spectra of common types of lights can be found at:

http://isaac.exploratorium.edu/~pauld/summer_institute/summer_day9spectra/spectra_exploration.html

Ask students what differences they notice between the solar spectrum and the spectrum of the artificial light. Prompt them, if necessary, with the question "Are all of the ROY G BIV colors present in this new spectrum?" For mercury fluorescent lights, there will only be a faint continuum, but there will be four or five bright lines (depending on how far red your eyes can see): 1 or 2 will be red, 1 will be green, and 2 will be blue/violet. Some colors are missing, and there are very clear lines – these lines are the fingerprint of mercury. If you see these lines, there is mercury in your light source. If you don't see them, there is little or no mercury. This is how astronomers figure out what distant objects are made of – every atom and molecule has its own unique fingerprint, and based on the brightness of the "fingerprint", we can even tell how much of an atom or molecule is present (lots of "stuff" means bright lines, very little "stuff" means faint lines).

3. If time and resources permit, you can show students other light sources containing other molecules and elements (e.g. with discharge tubes) to show them what some of the other fingerprints look like. Regardless, you should send students home with their spectroscopes and encourage them to check out the lights in their local neighborhoods – most street lamps are either mercury or sodium lamps, and "neon" signs often contain many different elements which produce different colors (only the orangey-red ones are actually neon). The website mentioned above would be a useful guide for their own explorations.

Remind them again NEVER to look at the sun!

Supernova Explosions Talking Points

These are some ideas for how to get the discussion rolling at the beginning of this session. Ask the questions (or ones of your own) and see what their ideas, preconceptions, and level of knowledge are.

Questions to ask:

Supernova Explosions

Summary

Students are reminded that the universe is made up of elements and that the heavier elements are created inside of a star. They are introduced to the life cycle of a star and how the mass of the star affects the process of fusion and the outcome of the star. The physical concept of balancing forces is discussed and an experiment is conducted to show what can happen to a soda can when the interior and exterior forces are not in equilibrium. An analogy is made between this experiment and core collapse in stars. Finally, it is demonstrated how mass can be ejected from a collapsed star. This is how the heavier elements are dispersed throughout the universe in a supernova explosion.

Purpose

To understand the life cycle of a star and the origin of the heavy elements in the universe.

Audience

Approximately 20 students (grade range 6^{th}-9^{th}) in a group works well

Objectives

- To introduce the life cycle of a star
- To discuss the forces at work inside a star
- To understand the role of mass in determining the extent of fusion and the fate of a star
- To learn about core collapse of a star
- To simulate mass ejection and understand how to populate the universe with the heavy elements from the interior of stars during a supernova explosion

Badge Requirements

-

Materials

- colored balloons (1 of each of the following colors: red, orange, yellow, green, blue, and violet)
- empty aluminum soda can (needs to be clean; we recommend having an extra)
- hot plate (or Bunsen burner and screen/ring setup)
- large bowl of cold water (the colder the better; ice helps)
- tongs or oven mitts
- Hoberman sphere
- basketball (or soccer ball)
- tennis ball
- different colored balls of clay – some to represent hydrogen, some to represent helium (optional)

Preparation

It is a good idea to practice the imploding can trick before you are called upon to perform in front of students. Make sure that you can see a good stream of steam from the can before inverting it onto the water. Very cold water works best, and it's a good idea to have two cans set to boil in case one does not work.

Activity

This activity can be completed in 45 minutes. A sample script and flow of discussion follows. It takes a while for the water in the can to boil, so it's a good idea to start it heating before starting the activity, or have a helper set it up ~15 minutes before you get to that part of the activity.

I. Review the concept of elements (approximately 10 minutes)

As the activity begins, ask the students what they have learned about elements in the universe (if they have already participated in the Elements and You activity) or what they know about elements (if they have not participated in the Elements and You activity). Remind them that the elements of which they are made (carbon and oxygen, for instance) are very rare in the Universe and are made in stars. They should know that the stuff created inside stars needs to get out somehow (in a big explosion). Try to ask them questions and unearth any possible misconceptions before the rest of the activity begins. What is an element? What are different kinds of elements? What is an atom? What is an atom made of? (Possibly a misconception will be the distinction between an atom being the smallest unit of an element, but not the smallest unit of matter. Atoms are made of protons, and neutrons, and have electrons orbiting around them.)

In this activity, and with your help, we are going to figure out how to make a star EXPLODE in order to distribute different elements into the universe! Not all stars will become supernovae, so first we need to understand the life cycle of stars... (Be careful with this. We tend to anthropomorphize stars, and people get the impression that they are alive.)

II. Stellar Life Cycle *(approximately 10 minutes)*

How do different sized stars behave and how do they age?

(Ask the students about what they know about pressure. What is pressure? What kinds of pressure do you know about?)

A key concept to reinforce is that there are different types of pressure at work in a star – two of these are pressure from gravity and gas pressure from hot material. Most important is that the (self-)gravity of a star is trying to push everything down, and other types of pressure fight it.

1. All stars start fight gravity by releasing large amounts of energy through fusion. Fusion is the process stars use to create different types of elements. Lighter atoms join together to create heavier atoms and release energy. This is a complicated process, but we can think of it simply. (Use clay balls to demonstrate how Hydrogen becomes Helium. Mention that it's actually a complicated process with four Hydrogen

atoms, but do not go further than that. A description of the p-p chain will be too much, unless you have a *very* advanced group.) The more mass that a star has, the hotter it can get in its core, and the more it can use energy from fusion to support itself from collapse, because the pressure from the fusion energy pushes outward against the gravitational pressure pushing inward. (This is a little bit like a pot of water boiling on the stove. The energy from the fire heats the water, making the water boil, push upward, and make steam that pushes up and out of the pot.) Bigger stars can fuse heavier and heavier elements (up to Iron), creating layers of different elements like an onion skin. (They should have seen this in the Elements and You activity. It is helpful to have the model star to refresh their memories.) We'll talk about Iron more in a few minutes.

2. Ultimately, all stars will loose the ability to fuse elements, because they run out of elements that they can fuse. At this point, the core may be dense enough to support itself – the gravity pushing down is not strong enough to crush the core. (The following description (adapted from http://www.adlerplanetarium.org/) demonstrates at what stage a star looses this ability to fuse elements and whether the star is light enough to support itself by other means.)

3. So, what are the different kinds of stars, and what happens to them? The way a star changes over time (or evolves) depends completely on the mass it has when it forms. Now, we'll look at how massive and how big stars can be and what happens to them over time. Ask the students whether they think the most massive stars will be the hottest or the coolest. Ask them what colors of light come from the hottest and the coolest things. Have six students blow up balloons according to the table below. (If you want to insert another color to include A stars, use VIBGYOR=OBAFGKM, letting "indigo" be B stars [black or dark violet will do if dark blue is not available] or WVBGYOR=OBAFGKM, letting white be O stars. The A balloon should be blown up to something like 8 in.)

   {Note to Astronomers: We use table B1 from Gray to roughly convert balloon color to size.}

   (Note to Classroom Leader: This is a table of Main Sequence (ordinary stars that shine because of fusion) – NOT evolutionary states)

Spectral Class	Relative Mass	Balloon Color	Relative Radius	Balloon Diameter	Comments:
O	23	Violet	7.4	19 in	Fuse → Fe – run out of fuel
B	8	Blue	4.3	10.5 in	Supernova → Black Hole
A, F	1.6	Green	1.4	4 in	Supernova → Neutron Star
G (SUN)	1	Yellow	1	2.5 in	Fuse → O – stable "white dwarf"
K	0.8	Orange	0.8	2 in	
M	0.4	Red	0.6	1.5 in	Fuse → H, He – stable, cool

Red/Orange Stars: These are very cool stars. They can fuse hydrogen into helium, but not much else. The helium in the core won't get hot enough to fuse together. The star will cool off and become fairly useless. The same kind of pressure that keeps us from sinking into the ground due to gravity will hold up the star against gravity until the end of time.

Yellow/Green Stars: These stars are similar to our Sun. They can fuse hydrogen into helium. It can also get hot enough to fuse the helium in carbon and oxygen, also lithium, boron, and beryllium. But, that's all. The star can't get hot enough to fuse carbon or oxygen into heavier elements, but the star is light enough that the dense carbon/oxygen core can support the star. This is called a white dwarf. No supernova here.

Blue/Violet Stars: Now we are getting somewhere! This is a really hot and really massive star, and it can do all the things the other stars can do and more! Fusion of elements will continue until the core is iron. But here, we run into two problems: (Ask students what these might be.)

i. Iron can't fuse into anything else (they may have learned this in the Elements and You activity).
ii. The star is too massive to be supported by the iron core in the same way the other stars are.

So we've reached a breaking point. The iron core is going to get hotter and hotter and hotter until, through a complicated process, the Iron atoms come apart into the smaller components. At this point, we have a sudden loss of support, and a lot of vacant space (since neutrons are much smaller than atoms).

III. Implosion *(approximately 10 minutes)*

Why do Stars Collapse?

The core of the blue/violet star now has no way supporting itself against gravity. So what happens when there is a sudden decrease in pressure that supports the core?

Demonstration of Core Collapse
(adapted from http://chandra.harvard.edu/graphics/edu/formal/demos/contraction.pdf)

> Place approximately two tablespoons of water in an empty aluminum soda can. Set the can on a hot plate or a screen/ring setup over a Bunsen burner. Heat the can until the water starts to boil. When the steam starts to come out of the opening in the top of the can, quickly pick up the can with an oven mitt or tongs and invert into a bowl of cold water. The can will instantly implode with a crunching sound.
>
> Related Physics – Can Implosion Demonstration: The empty aluminum can is held in equilibrium by the pressure of the air inside the can directed outwards and the pressure of the air outside of the can directed inwards. Heating the water in the can causes the water to turn into steam. The steam drives all of the air out of the

can. Now the can is held in equilibrium by the pressure of the steam pushing outwards (analogous to the radiation pressure in the core of the star) and the pressure of the air outside of the can directed inwards (analogous to the gravity of the star directed inwards). When the can is inverted over the cold water, the steam instantly condenses. (This is similar to the sudden "condensation" of electron degenerate matter to neutron degenerate matter.) Now there is no pressure inside the can, and since the opening of the can is against the water, air cannot rush back inside to compensate. The outside air pressure then causes the can to implode (analogous to the core of a star collapsing without radiation pressure as a counterbalance to gravity.)

Related Physics – Collapsing Hoberman Sphere: So we saw that the can imploded because the pressure inside the can disappeared. So why do we get an explosion? Here we have a cool plastic sphere (show them the Hoberman sphere), and we can use it to simulate the imploding core of a star. (Open the sphere all the way, and then let it collapse under its own gravity. – You can have a student do this.) So what happened after the sphere collapsed? That is right, it "bounced" at the end. (The bounce can be a little difficult to see. You'll probably want to show them the collapse and bounce a few times.) It started to collapse, but then the collapse stopped because stuff falling in from one side collided with the stuff falling in from the opposite side.

IV. Mass Ejection *(approximately 10 minutes)*

How does the materials from the interior of a star find if way out?

Now the core of star collapsed, and then bounced when it collided with itself. But a star is made up of more than merely a core, it also has an atmosphere like the Earth, only much thicker. So when the core collapses, what happens to the atmosphere?

<u>Demonstration of Atmosphere Ejection</u>
(adapted from http://chandra.harvard.edu/graphics/edu/formal/demos/ejection.pdf)
(You can let students try this, but be careful with the tennis ball's rebound!)

First drop the tennis ball and basketball individually on the floor so that the students can see how far above the floor the basketball and the tennis ball rebound. Then place the tennis ball on top of the basketball and hold them out in front of you. Let go of both balls at the same time so that they fall towards the floor together. When the two balls hit the floor the tennis ball will suddenly rebound with enough energy to hit the ceiling.

Related Physics: When the core of the star implodes it contracts catastrophically, just like the imploding can. At the end of the contraction the material in the core comes together with such a large amount of force that it rebounds. As the core (The basketball represents the outer part of the core – Be careful that the students know what you mean. They might think that the basketball is the core, and the core somehow falls as a whole or moves in some direction) contracts, all the outer atmospheric layers (represented by the tennis ball) are also contracting and following the core. They are less dense and take a little longer to contract than the core. (Be sure to explain what you mean by atmosphere. Students probably haven't thought about atmospheres in terms of stars, and we don't want them to come away with the idea that stars have clouds and air around them!) When the core (basketball) rebounds, the atmospheric layers (tennis ball) are still in-falling towards the core. The rebounding core meets the incoming atmospheric layers with enough energy to literally blow the atmospheric layers away from the star due to the transfer of momentum from the basketball to the tennis ball. This is the supernova explosion.

V. ***Wrap-up*** *(approximately 5 minutes)*

- Not all stars will end their lives in a spectacular supernova. Without help, only the ones that are massive enough to try and fuse iron will do so.
- Every star is fighting against gravity, and they start doing this using the energy released by fusing hydrogen into helium. Some stars will only get this far, and those will end up fighting gravity the same way the ground fights gravity, keeping us from falling to the center of Earth.
- Other stars can get hot enough to fuse helium, etc. The hottest/most massive stars will get to the point where they have an iron core, but this is a problem because iron doesn't fuse and stars are too massive to be supported the other way.

- There is a sudden drop in the core pressure of a massive star, and the whole thing will start to implode. Stuff in the core and bottom of the atmosphere will "bounce" when it meets other stuff falling in from the other side, and this bounce will cause the outer layers of the atmosphere to violently explode (fly outward). In the remaining core, the neutrons might be able to hold up what's left. This is what's called a neutron star, and it can be observed in the X-rays. If the remainder of the core is too massive even for neutrons, it will become a black hole.
- (Most stars have companion stars. Sometimes yellow stars can become supernovae if they have a companion which helps them by adding more mass – the same way you can collapse a table pile up enough stuff on it.)

Supplementary Information

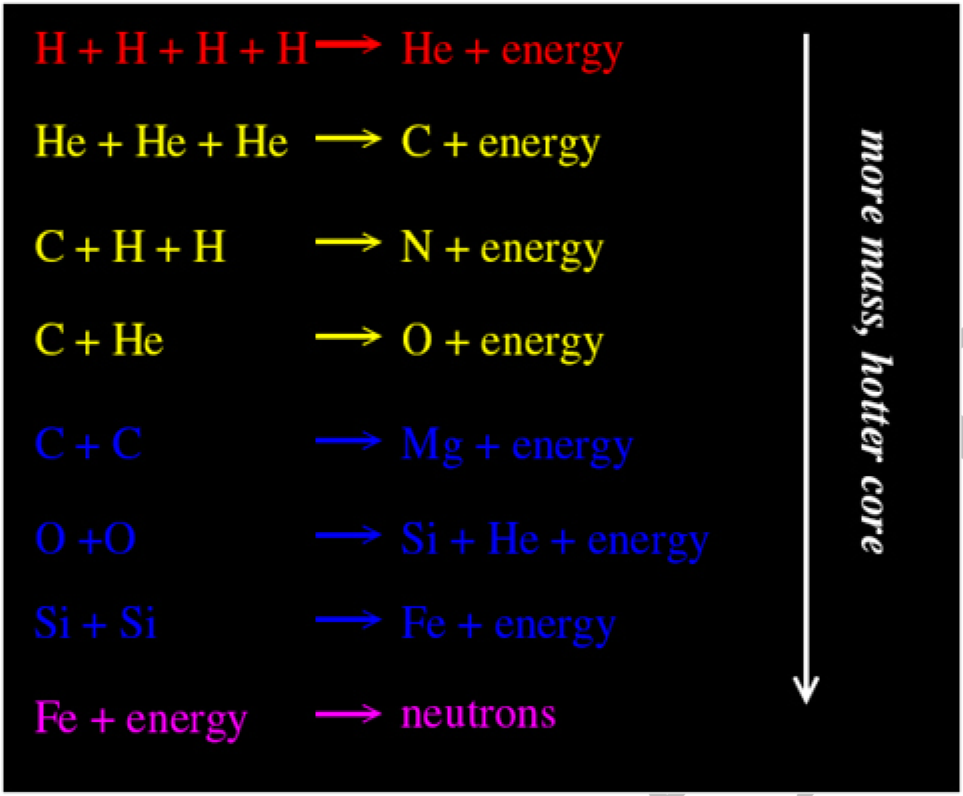
WARNING - Most of this is at a higher level than should be needed and is only for extra information for the further understanding of the instructor, answering questions, or adapting to a more mature audience.

SPECTRAL TYPES:
*** If you mention the names of the spectral types, the students might ask about OBAFGKM ***Astronomers classify stars by their spectra – the colors of light they emit. Most stars actually emit many kinds of light, but a star can look one color, because that is the brightest part of its spectrum. When people first started looking at the spectra of stars, they looked especially at the amount of light coming from Hydrogen. They called the stars with the most Hydrogen emission type A, then type B, C, and so on. Later, people realized that thinking of classes of stars by what color they were made more sense and gave more information, because the bluest are also the hottest, brightest, and most massive, while the reddest are the coolest and least massive. So, the classes (A, B, C…) were reordered, and some of them dropped out, and we ended up with OBAFGKM (from blue to red, hot to cool, high mass to low mass).

Some kinds of stars or other astronomical objects are brightest in colors that we cannot see with our eyes, but that does not mean that they do not put out some light in the optical. (They may have talked about different kinds of light in the Rainbow Analysis Activity.) Astronomers have special cameras and telescopes that can look at different kinds of light to study different astronomical objects. Sometimes people also use these cameras on Earth. "Night Vision Goggles" might let people see infrared light.

FUSION Processes :
This table shows simplified versions of the fusion processes that occur in different mass stars. The colors mostly correspond to the colors in the table Stellar Life Cycle section of this description. However, violet in the Stellar Life Cycle table represents the very largest,

hottest, most massive stars. Here, violet represents the end stage of these very massive stars, in the Super Nova collapse.



Red stars are the coolest and can only fuse Hydrogen to Helium (also some Lithium, Beryllium, and Boron).

*** Students are likely to ask what will happen to the Sun. Here is a bit more than is included in the main description *** Stars of intermediate are yellowish (like the Sun) and can fuse Hydrogen to Helium and then fuse to Carbon, Nitrogen, and Oxygen (also some Lithium, Beryllium, and Boron). Stars with masses less than about 1.44 times the mass of the Sun "explode" in a Nova (like a Super Nova but smaller) and become Red Giants. The part that collapses cannot fuse past Carbon, Nitrogen, and Oxygen, so it collapses more. Eventually, it stops collapsing because of Electron Degeneracy Pressure (from the Pauli Exclusion Principle) that means more than one electron cannot be in the same energy state unless there's a lot of pressure added. These stars get stuck as White Dwarfs and are kept from collapsing by this degeneracy pressure. The Sun will make a White Dwarf about the size of Earth.

The very hottest stars appear Blue and can continue the process of fusion (in shells, as described in the Elements and You activity) until they fuse to Iron in their cores.

Iron is the most stable element, so it is very difficult to fuse into more massive elements. More energy is needed to start the process than comes out of the fusion. These fusions do occur sometimes in the cores of stars, but their net result is to absorb energy rather than release it. They cannot happen very often, and they definitely cannot make a star shine. We know they happen once in a while, because we have elements that are heavier that Iron (which is only number 26 on the Periodic Table). This is why these heavier elements are *so* rare in the universe (on average).

Once the core of one of these very massive stars has enough Iron, the core cannot support the weight of the outer parts of the star, and collapse occurs as described above. The collapse adds energy to the left over core of the star. This makes the electrons and protons in the Iron atoms combine to form neutrons (the Violet step in the table above). Since neutrons are much smaller than the Iron atoms as a whole, the whole thing collapses even more.

Stars between about 1.44 and 3 Solar masses stop there. The remaining core after the Super Nova is full of neutrons and is supported by Neutron Degeneracy Pressure, making a Neutron Star. This is just like a White Dwarf being supported by electron degeneracy.

Stars that are heavier than about 3 Solar masses become Black Holes. There is so much pressure and energy in these collapses that they overcome the neutron degeneracy pressure, pushing the neutrons closer and closer together, until there is no pressure pushing outward to fight the gravitational pressure that pushes inward.

Black Holes in Orbit Talking Points

These are some ideas for how to get the discussion rolling at the beginning of this session. Ask the questions (or ones of your own) and see what their ideas, preconceptions, and level of knowledge are.

Questions to ask:

What do you know about black holes?

Briefly introduce the concept of a black hole as an object that has a huge mass but is very small (i.e. has incredibly high density). Imagine the mass of a star, but scrunched into the size of a city.

Why are black holes black?

If black holes are black and space is black, how do we find them?

Black Holes in Orbit

Summary

Students are introduced to the basic properties and behavior of black holes through a brief discussion, including how it might be possible to detect black holes through their interaction with other stars. Then they "act out" binary star systems in pairs, walking slowly around one another in a darkened room with each pair holding loops of wire to simulate the gravitational interaction. Most of the students are wearing glow-in-the-dark headbands to simulate stars. Some are not wearing headbands and represent black holes. A small set of the black holes have flashlights to simulate X-ray emission.

Purpose

To teach some of the properties of black holes and how they interact with normal stars.

Audience

Approximately 20 students (grade range 6^{th}-9^{th}) in a group works well

Objectives

- To learn the basic properties of black holes, including:
  - Escape velocity
  - Gravitational interactions
  - Accretion disks
- To consider black holes less mystifying
- To brainstorm ways to observe objects or phenomena which cannot be seen directly
- To be introduced to basic X-ray physics

Badge Requirements

-

Materials

- 1 tennis ball
- 5-6 loops of heavy gauge wire, ~ 36 inches in circumference
- 5-6 loops of heavy gauge wire, ~ 60 inches in circumference
- paper headbands (1 per student)
- glow-in-the-dark stickers and/or decorations
- tape or stapler
- 6 flashlights and batteries
- red cellophane to cover flashlight lenses
- tissue paper party decorations – 2 large (~ 8 inch diameter) balls, 1 large (~ 24 inch diameter) disk
- room with adequate space to move around for the activity
- completely blacked-out room (optional)

Preparation

3. Wire loops: approximately 10 minutes
   Cut and shape the wire into 5-6 medium sized loops (approximately 36 inches in circumference) and 5-6 large loops (approximately 60 inches in circumference)

4. Decorate the headbands (this can be done in advance or with the students): approximately 10 minutes

5. Darken the room: approximately 10 minutes
   The room should be capable of going from brightly lit to dark so that the glow-in-the-dark headbands can be seen effectively. Sometimes this means lights or light leaks must be covered. Dark black plastic trash bags and duct tape have proved useful for this.

Activity

This activity can be completed in 45 minutes. A sample script and flow of discussion follows.

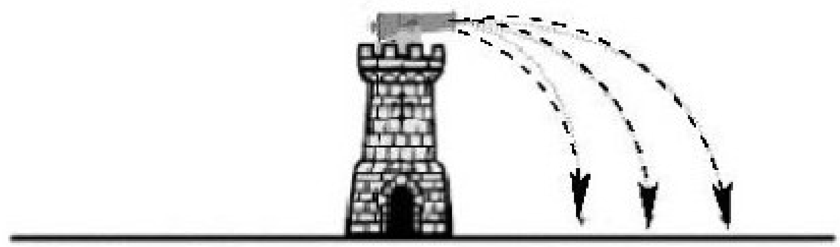
I. What is a Black Hole? (approximately 10 minutes)

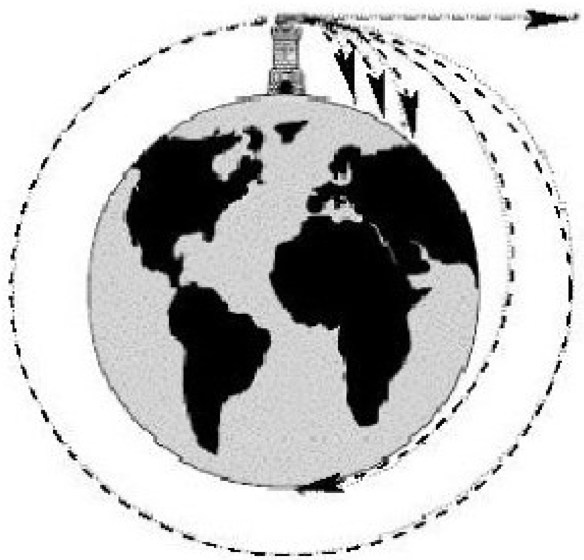
The leader explains Black Holes (BH's) based on the following points:

i. Concept of an orbit: Earth and the other planets orbit the Sun; two stars orbiting each other are known as binary stars. (Helpers can demonstrate orbiting stars using big balls or one of the wire loops used for the activity.) Point out that roughly half of the stars visible in the sky are binary stars, so it is relatively common.

ii. What is a BH? Explain concept of escape speed considering a tennis ball on earth – how hard must I throw this ball for it to go into orbit. Now if I am on the moon, how hard must I throw to get the ball into orbit around the moon? [Use image of a cannon on a very tall tower to help illustrate how throwing something harder could put it into orbit.] Then explain BH by explaining that the escape speed from a BH is greater than the velocity of light and therefore nothing (not even light) can escape from inside a BH.

Escaping Gravity





Source: http://www.adlerplanetarium.org

iii. How would you observe a BH? After all, if even light cannot escape a BH, how can they been 'seen'? Explain that BH's are observed by the effect of gravity, i.e. by observing stars and other materials apparently orbiting around nothing that can be seen. [This can be demonstrated by the leader explaining "If I were a BH and I was close to a normal star, say you (standing close to one of the students), what do you think the effect would be?]

iv. Explain accretion disks: materials spiraling in (why does it spiral?) and light emitted by that heated material (why is it heated? answer: friction) is observed by us. Explain that a lot of such light emitted close to the BH is in X-rays and why. Demonstrate what this looks like with the tissue paper disk and ball from the kit. [Use image of an artist's conception of an accreting black hole to help with the visualization of an accretion disk.]

Note:

If the students have already seen a movie describing black holes, it may be sufficient to discuss the above ideas only briefly and instead answer questions or discuss common misconceptions – i.e. black holes are NOT cosmic vacuum cleaners, time does NOT stop inside them, etc.

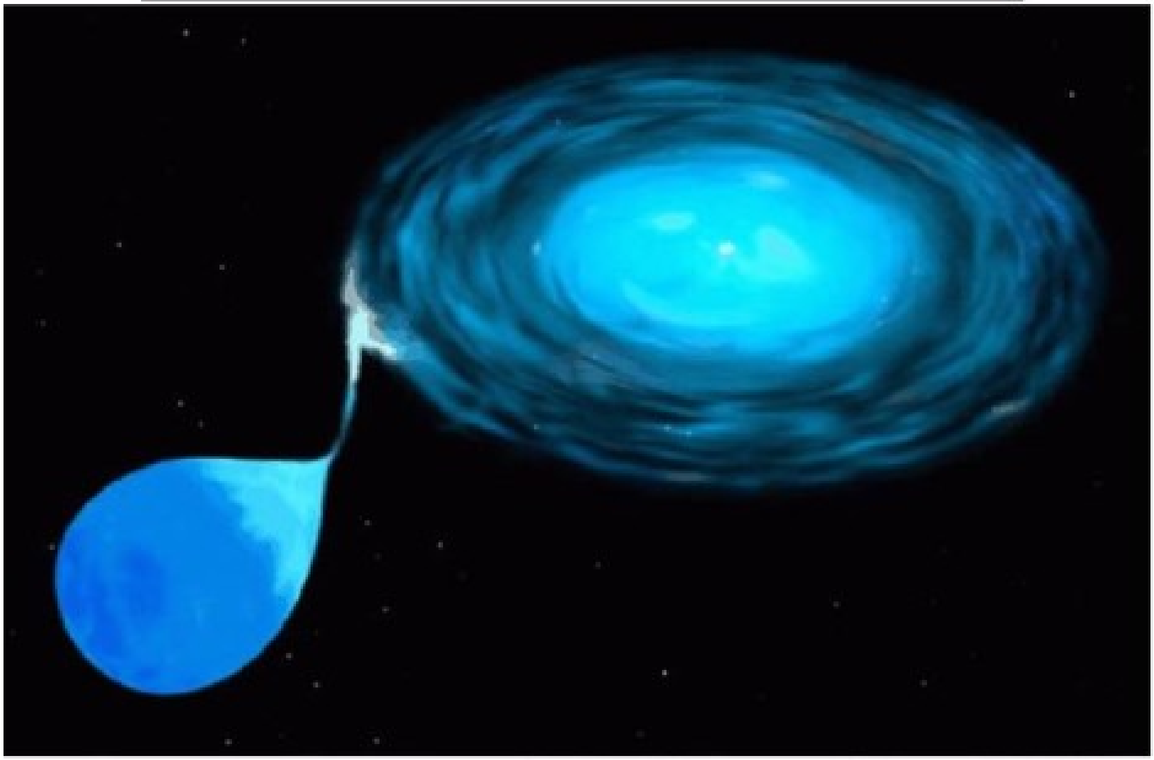
II. Kinesthetic Activity *(approximately 20 minutes)*

Explain the activity to them. Some of them are going to be normal stars, without a pair, moving through the galaxy (2 or 3 students), some of them are going to be normal binary star pairs (2 or 3 pairs) and some are going to be normal star & BH binaries (2 or 3 pairs) – the latter which will be observable only with their 'X-ray' eyes. Give all the normal stars a glow-in-the-dark headband and the BH's a flashlight. Give the binary star pairs a large loop of wire and the star/BH binary pairs a medium sized loop. The idea here is that with the closer binary systems, the star and BH are close enough for accretion to take place, i.e. the star "donates" some of its mass to the BH, and X-rays turn on. Practice once with the lights on what everyone is supposed to do. It is useful to have a helper stationed by the light switch who can make the room go dark at will. Make sure you tell them to move slowly in circles around each other or move slowly around the classroom (for the single stars) and reposition students as necessary to avoid collisions. The stars in binary systems with BH's must move much slower than normal binary stars. Then turn off the lights and first observe with 'normal' eyes (without flashlights being turned on). Then, say 'Turn on your X-ray eyes' and the BH's should turn on their flashlights at this time. Ask the students to observe both with 'normal' eyes and 'X-ray' eyes. After this turn lights back on. It may help to redistribute the flashlights so that more students can have a turn as a BH.

III. Wrap-up *(approximately 10 minutes)*

Ask them questions based on this activity. An example is: how do you identify BH's? While the leader does this, the helpers should go around and collect the headbands, flashlights, and wire loops. Past experience indicates that this question-and-answer session doesn't always work.

An Accreting Black Hole



Credit: Astronomy Picture of the Day
http://antwrp.gsfc.nasa.gov/apod

Appendix A: Materials Checklist

This checklist will help you assemble and review your supplies for each session. Quantities of each item are not listed, as that will be determined by the size of your group. Additional details about the materials needed are available in the session write-ups.

Elements and You

❒ Examples of a pure elements (copper, aluminum, lead, etc.)
❒ Pound cake
❒ Knife
❒ Napkins or paper plates
❒ Large periodic table to display
❒ Large mixing bowl
❒ Rice
❒ Unpopped popcorn
❒ Macaroni
❒ Uncooked beans
❒ Uncooked black-eyed peas
❒ Multi-colored cake decorating sprinkle shapes
❒ Scoops or Dixie cups
❒ Trail mix key
❒ Red modelling clay
❒ Yellow modelling clay
❒ Orange modelling clay
❒ Green modelling clay
❒ Blue modelling clay
❒ Model star clay colors key
❒ Trash can or trash bag

Rainbow Analysis

❒ Paper towel tubes

❒ Aluminum foil
❒ Masking tape
❒ Diffraction grating
❒ Example spectrum (poster, etc)
❒ Discharge lamps (optional)
❒ Completely blacked-out room (optional)

Supernova Explosion

❒ Colored balloons
❒ Empty soda cans
❒ Hot plate (or Bunsen burner and screen/ring setup)
❒ Heavy oven mitts or tongs
❒ Large bowl
❒ Cold water
❒ Hoberman sphere
❒ Basketball
❒ Tennis ball

Black Holes in Orbit

❒ Tennis ball
❒ 36 inch circumference loops of heavy gauge wire
❒ 60 inch circumference loops of heavy gauge wire
❒ Paper headbands
❒ Glow-in-the-dark stickers and/or decorations
❒ Tape or stapler
❒ Flashlights with batteries
❒ Red cellophane to cover flashlight lenses
❒ Tissue paper party decorations
❒ Room with adequate space to move around
❒ Completely blacked-out room (optional)

Appendix B: Shopping Suggestions

The activities in *Big Explosions and Strong Gravity* are designed to utilize readily accessible materials – most items can be purchased at a supermarket, mass merchandiser, or craft store. A few items are exclusively available through specialized suppliers, and this section provides detailed information about purchasing. This should be taken as suggestion only, and by no means as an exhaustive list.

Elements and You

This session uses examples of pure elements to guide student discussion about what an element is and what the differences between elements are. The simplest way to do this is to buy one of the science density kits that are out there and include cubes or cylinders of the same size made out of different metals (or alternately of the same mass and therefore different size, but having one of these remain constant will help with the comparison). Most of these kits will include materials that are not examples of elements, so this is something to watch out for.

- Uniscience Laboratories (http://www.unisciencelab.com/) has several options that will work with only the inclusion of brass as a non-element (look under Mechanics and then Cubes and Cylinders).
    - Metal Cubes
        - 10 mm sides
            - 3510-11: Aluminum
            - 3510-12: Brass
            - 3510-13: Copper
            - 3510-14: Iron
            - 3510-15: Lead
            - 3510-16: Zinc
            - 3510-01: Set of 6
        - 20 mm sides
            - 3510-21: Aluminum
            - 3510-22: Brass
            - 3510-23: Copper
            - 3510-24: Iron
            - 3510-25: Lead
            - 3510-26: Zinc
            - 3510-02: Set of 6

        - 25 mm sides
            - 3510-03: Set of 6
        - 32 mm sides
            - 3510-04: Set of 6
            - 3520-01: Aluminum (with hook)
            - 3520-02: Brass (with hook)
            - 3520-03: Iron (with hook)
            - 3520-04: Lead (with hook)
            - 3520-05: Copper (with hook)
            - 3520-06: Zinc (with hook)

    - Cylinders
        - 3523-00: Set of 5 (aluminum, lead, copper, brass, and zinc) of same mass and diameter but NOT length
        - 3525-01: Set of six 10 x 33 mm cylinders
        - 3525-02: Set of six 10 x 40 mm cylinders

- Science Kit and Boreal Laboratories (http://sciencekit.com/) has a set of equal mass (but not equal size) cubes in copper, aluminum, zinc, iron and brass.
    - Item #: WW4800900

Rainbow Analysis

This session requires diffraction grating, a thin plastic film available from Learning Technologies or Educational Innovations. See contact information above. Purchase at least 1 square inch per spectroscope.

Learning Technologies Item:
- PS-08A: Holographic Diffraction Grating (2 sheets, each 5 x 5 inch)

OR

Educational Innovations Item:
- PG-400: Single Axis Diffraction Grating (6" x 24" sheet)

Supernova Explosions

This activity uses a Hoberman sphere, which can be purchased at Toys 'R Us and other toy stores.

Periodic Tables

We have ordered our laminated periodic tables from

- http://scientificsonline.com/product.asp?pn=3053431&bhcd2=1207752820
- Additionally, notebook paper sized period tables as handouts can be found at the following sites:
- http://www.schoolmasters.com/categories/productDetails.cfm?product_ID=15027&div=sc&category&bc3&details
- http://sciencekit.com/product.asp?pn=IG0019981&sid=2008FS&eid=2008FS&mr:trackingCode=9CE4179D-D605-DD11-AD5F-000423C27502&mr:referralID=NA&bhcd2=1207753692

Big Explosions and Strong Gravity

A Day of Exploration into Supernovae and Black Holes

Saturday, April 26th, 2008

8:45 a.m. - 9:00 a.m.	Registration
9:00 a.m. - 9:30 a.m.	Greeting/Orientation (big room/Universe Room)
9:30 a.m. - 10:25 a.m.	Group A: Rainbow Analysis (Galaxy Room) Group B: Rainbow Analysis (Nebula Room) Groups C & D: Elements and You (Universe Room)
10:30 a.m. - 11:25 a.m.	Groups A & B: Elements and You (Universe Room) Group C: Rainbow Analysis (Galaxy Room) Group D: Rainbow Analysis (Nebula Room)
11:30 a.m.	Black Hole activity (Universe Room)
12:15 p.m.	LUNCH + Astronomy Question Scavenger Hunt (Universe Room)
1:15 p.m. - 1:55 p.m.	Group A: Supernova Explosions (Galaxy Room) Group B: Supernova Explosions (Nebula Room) Groups C & D: Black Holes in Orbit (Universe Room)
2:00 p.m. - 2:40 p.m.	Groups A & B: Black Holes in Orbit (Universe Room) Group C: Supernova Explosions (Galaxy Room) Group D: Supernova Explosions (Nebula Room)
2:45 p.m. - 3:00 p.m.	Evaluations and T-shirt Distribution (Universe Room)

Appendix D: Astronomy Question Scavenger Hunt

RULES:

1. Have fun! This is your chance to interview professional astronomers.
2. Respect everyone's right to eat their lunch. There is no extra credit for finishing first.
3. Don't ask the same astronomer more than one question.
4. Only ask astronomers with the "ASK ME!" stickers. They are your targets!
5. Try to keep the Q&A one-on-one rather than groups-on-one.
6. **Have the astronomer initial your answer after you write it down.**
7. Once you finish the list, go sign up for the prize drawing.

QUESTIONS:

___ 1. Where were you born, or where did you grow up?

___ 2. When (at what age) did you decide you wanted to become an astronomer and why?

___ 3. Where were you when you were my age? (you have to tell the astronomer your age!)

___ 4. When you were very young, what did you want to be when you grew up?

___ 5. What did you do to prepare yourself for becoming an astronomer? (in high school, in college, etc) What is/will be your highest college degree?

___ 6. What are your non-astronomy hobbies?

___ 7. Can you tell me the name of one of your favorite astronomical objects? How did it get that name?

___ 8. What pets do you have, if any? If not, what might you want to have as a pet?

___ 9. What would be your dream vacation?